Fish Without Borders: Trends in the Status and Distribution of Groundfish in the Transboundary Waters of Washington and British Columbia

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Abstract
Between 1997 and 2001, the Washington Department of Fish and Wildlife conducted a series of bottom trawl surveys in the southern Strait of Georgia, San Juan Islands, and eastern Strait of Juan de Fuca. The survey goal was to estimate the abundance of demersal fishes and macroinvertebrates in the Washington and adjacent British Columbian portions of the transboundary waters. The spring-time surveys consisted of trawling at stations that were stratified by depth and selected on a systematic or random basis. At each station, a research bottom trawl fitted with a fine-mesh codend liner was towed from a chartered fishing vessel for approximately 10 minutes at a speed of 1.5 to 2 knots. In all, 170 trawls were conducted in Washington portions of the survey area, and 119 stations were occupied in the British Columbian portion.

In 1997 and 2000, extensive and synoptic surveys of the Washington and British Columbian Straits of Georgia and Juan de Fuca revealed that fish biomass was roughly distributed between the two areas in proportion to the area surveyed. However, individual species were not proportionately distributed. Species with affinities to shallow and unconsolidated sand and mud substrates were relatively more abundant in the Washington survey area where these habitats were more frequent. Species frequenting harder substrates were correspondingly more common in the British Columbian and San Juan regions where these habitats were more common. Groundfish populations increased in the Washington Strait of Georgia from 11,000 mt in1997 to 18,000 mt in 2001. A long-term declining trend in total fish abundance was evident in the Washington Strait of Juan de Fuca.

Several distinct patterns in transboundary distributions were observed that have implications for coordinated fisheries management between the United States and Canada. In the Strait of Georgia, the deep Malaspina Trough confines shallow-water species to the rim around the basin. These species are less likely to be encountered by trans-border fisheries. Deep-water species, however, were distributed along the international border making them vulnerable to fisheries on either side of the border. The banks and troughs of the eastern Strait of Juan de Fuca presented a different pattern of species distributions. Shallow and deep-water species were distributed on either side of the international boundary making them both likely to be encountered by transboundary fisheries.

Introduction
The Straits of Juan de Fuca and Georgia and adjacent archipelagos are extensive marine basins shared by Washington and British Columbia. Significant marine resources within these waters have undergone dramatic declines in recent years (West 1997), and the resources face an array of factors that threaten their survival (Mills 1999). Because of the differing nature of management between the United States and Canada, coordinated assessment and management has been difficult and prompted, in part, the creation of the Environmental Cooperation Agreement between Washington (WA) and British Columbia (BC). Few synoptic surveys of marine resources have been undertaken to examine the distribution and abundance of marine organisms between the two countries, but in recent years the Washington Department of Fish and Wildlife (WDFW) has conducted a series of bottom trawl surveys in the southern Strait of Georgia, San Juan Islands, and eastern Strait of Juan de Fuca in both Washington and British Columbian waters. The goal of these surveys was to estimate the abundance of demersal fishes and macroinvertebrates and to characterize their distributions in order to understand the need for coordinated management in these transboundary waters.

Methods
Between 1997 and 2001, WDFW contracted a commercial fisher to operate a research bottom trawl in a series of regional surveys. These surveys, conducted during the spring, consisted of trawling at stations that were stratified by depth and selected on a systematic or random basis. In 1997, the WA and BC Strait of Georgia from a line south of Horseshoe Bay and Nanoose Harbor was surveyed on a stratified systematic basis (Figure 1). In 2000, the eastern portions of the Strait of Juan de Fuca was surveyed on a stratified systematic basis, and 2001, the WA and BC Strait of Georgia were surveyed again but only south of the 49th parallel. In addition, a survey was conducted in the WA San Juan Archipelago and in the BC Haro Strait and Boundary Pass areas. The number of stations per stratum was based upon area of strata and measured

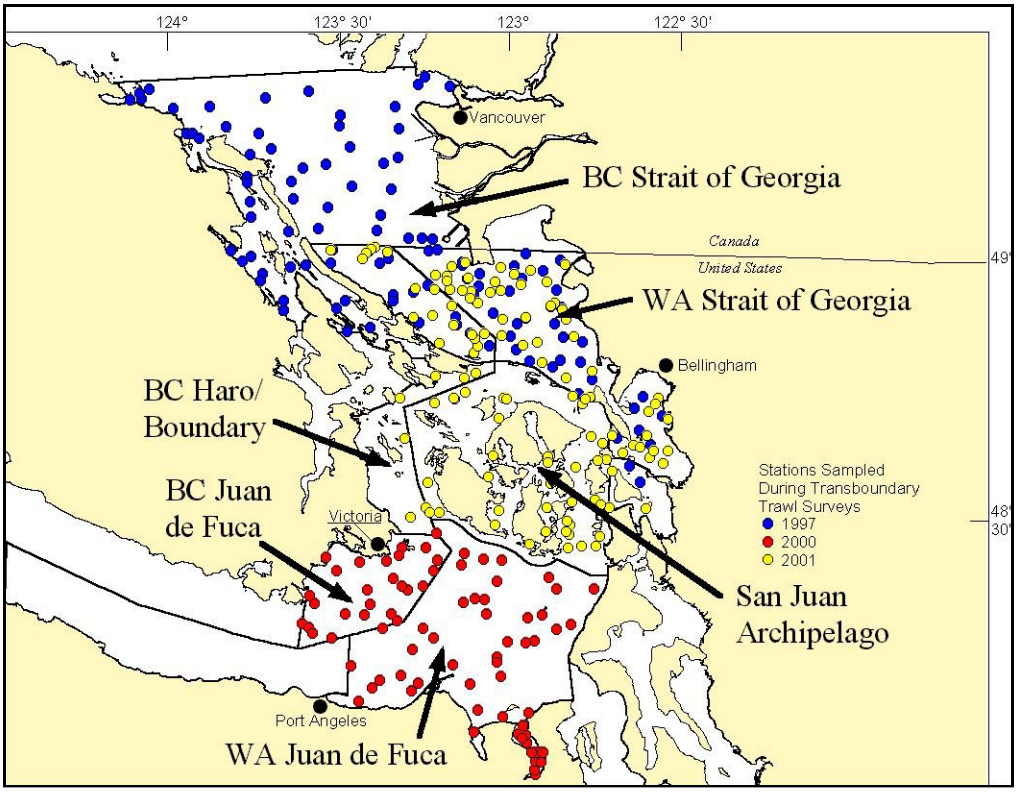

Figure 1. Transboundary survey regions and station locations.

variances of key groundfish species. Sample sizes ranged from 25 per region to 69 per region (Table 1). Most regions were stratified into four strata based upon depth: 5-20 fathom (fms), 21-40 fms, 41-60 fms, and 60 fms or greater. For the BC Strait of Georgia there were five depth strata that corresponded to the three shallowest strata in the other regions with the addition of 61-120 fms and 121 fms or greater.

The Fishing Vessel *Chasina*, a 17.7 m steel hull purse seiner, was chartered for the duration of the surveys. Its captain and crew piloted the vessel and operated the fishing gear. The vessel was equipped with a 400-mesh Eastern otter trawl made with synthetic twine. The main body of the net had meshes with an opening of 10 cm, but the codend of the net contained a liner with a mesh size of 3.2 cm. The head rope of the net measured 21.4 m and the 28.7 m foot rope was rigged with 13 cm "cookie gear" (tightly packed, non-moving, rubber disks) to reduce both wear and snags. The opening of the net under fishing conditions had previously been measured and was found to vary with both the depth fished and the ratio of wire paid out to the depth fished. The vessel was equipped with a video depth sounder, a differential Global Positioning System (dGPS), computer navigation, radar, and communications equipment.

The scientific crew processed the catch by identifying, counting, weighing, and recording each recognizable taxon. Anthropogenic debris collected by the net was separated and processed in a similar manner to the biological catch. Samples of key groundfish species were measured and subsamples retained for age determination, genetic stock analysis, and other purposes. All data were recorded into databases maintained by the WDFW. Data were error-checked after the trawl survey by comparing all computer data entries with data recorded on waterproof forms in the field. The data were processed into estimates of numerical and biomass abundance for each taxon and stratum.

Methods for estimating total abundances and associated variances are modified from Gunderson (1993) and are further explained for stratified random surveys in Schaeffer et al. (1979). The first step in estimation was determining the density of each fish and invertebrate taxon found at each station. The area swept for each station was determined by multiplying the net width by the distance fished. To determine density, the sample numbers or weights were divided by the area sampled at the station. For each stratum in each region, population abundance and biomass estimates were made from the observations of fish density averaged among stations, and variances were computed for the station observations of individual and biomass densities. Where f_{ij} is the i-th density observation (either in terms of numbers or weight) of n stations in the j-th stratum, and A_j is the area of the j-th stratum and N_j is the species population estimate of the j-th stratum:

$$N_j = A_j \overline{f_j} = A_j \sum_{i=1}^{n} \frac{f_{ij}}{n}$$

Regional estimates of numerical and biomass population abundances were made by summing the point estimates and their variances over the all strata. The variance of stratum population estimates was calculated as:

$$Var(N_j) = A_j^2 Var(\overline{f_j}) = A_j^2 \sum_{i=1}^{n} \frac{\left(f_{ij} - \overline{f_j}\right)^2}{n(n-1)}$$

Coefficients of variation were calculated as the percentage of the square root of the variance divided by the population estimate. Estimates of numerical population at length were obtained by multiplying the stratum estimate of the numerical population by the proportion of each length category in the sampled population. The proportion was determined by summing the product of the proportion of each length category in each trawl sample by the weighted contribution of the station density to the total density. Data management for estimates included compiling estimates of populations, variances, and percentages of the Coefficients of Variation (% CVs) for significant taxonomic categories or key species into two databases.

Results

Some 116 species of fish occurred among the three years surveyed. The synoptic bottom trawl surveys of the WA and BC Straits of Georgia and Juan de Fuca revealed that total fish biomass was roughly distributed among the areas in proportion to the area surveyed (Table 1). The 1997 survey of the BC Strait of Georgia resulted in the greatest population estimates of any region and the 2001 survey of the BC Haro Strait-Boundary Pass area, the least of any region (Table 1). Coefficients of Variation were less than 30% for most regional estimates but did exceed 39% in the BC Haro Strait-Boundary Pass region. The combined fish biomass for the extensive BC survey in 1997, the WA Strait of Georgia survey in 2001 and the Juan de Fuca and San Juan regions was 86,950 mt (6.8% CV) and the total abundance was 469 million individuals (11.9% CV). Spotted ratfish was the most abundant species among all regions constituting 50,000 mt and comprising 56% of all the total fish biomass. The biomass of flatfish was 16.8% of the total fish biomass and as a group was the second most abundant taxon. Of the flatfish, English sole comprised 42.9% of the biomass and was the most abundant flatfish species. The third most abundant species encountered in the bottom trawl survey was spiny dogfish (10.5% of the total biomass) followed by skates (3.6%) and sculpins (2.8%). However, individual species were not proportionately distributed. Species with affinities to shallow and unconsolidated sand and mud substrates were relatively more abundant in the Washington survey area where these habitats were more frequent. Species frequenting harder substrates were correspondingly more common in the BC and San Juan regions where these habitats were more common.

Five distinct patterns of species occurrence could be identified based upon the species distributions and depth stratification. A shallow-nearshore group consisted of 18 species characterized by cabezon, bay goby, Pacific staghorn sculpin, and sand sole. A shallow-water group consisted of 27species that were characterized by species such as starry flounder, southern rock sole, speckled sanddab, butter sole, c-o sole, and buffalo sculpin. There were two deep-water occurence patterns. One included 19 deep-water species generally restricted to the Strait of Georgia. These included Pacific whiting, black eelpout, pallid eelpout, brown cat shark, short-spine thornyhead, and splitnose rockfish. The other was a deep-water group distributed over the entire survey area consisting of 19 species and characterized by such species as Pacific cod, spotted ratfish, Dover and rex soles, and sandpaper skate. There were 29 species that were ubiquitous, occurring over most of the surveyed areas and depths. This group was characterized by species such as big skate, plainfin midshipman, and English and slender soles.

Discussion

The bottom trawl surveys were successful in obtaining consistent and widespread information to estimate total fish abundance with high precision. These surveys represent the first comprehensive surveys of benthic fishes and large invertebrates in the waters shared by British Columbia and Washington. The data and estimates that resulted from the surveys will be valuable for determining fishery potential and impact, planning for conservation, and achieving an understanding of the factors controlling fish and invertebrate distributions. The information can also serve as an environmental baseline for evaluating changes in the transboundary waters due to management actions, catastrophic or chronic habitat damage, or natural changes.

Table 1. Survey Areas, Samples Sizes, Population Estimates and Percent Coefficients of Variation

Year	1997	2000	2001
WA Strait of Georgia			
Area (ha)	87,642		87,642
Number of Stations	40		50
Total Fish Abundance (no x1000)	64,112.4		159,696.3
% CV	21.9%		32.0%
Total Fish Biomass (mt)	11,056.7		18,370.5
% CV	21.2%		21.3%
BC Strait of Georgia			
Area (ha)	214,190		36,147
Number of Stations	69		19
Total Fish Abundance (no x1000)	109,117.1		23,658.0
% CV	8.8%		19.7%
Total Fish Biomass (mt)	27,371.7		6,972.3
% CV	11.2%		17.8%
WA Eastern Strait of Juan de Fuca			
Area (ha)		140,163	
Number of Stations		40	
Total Fish Abundance (no x1000)		112,147.1	
% CV		15.2%	
Total Fish Biomass (mt)		18,952.3	
% CV		12.4%	
BC Eastern Strait of Juan de Fuca			
Area (ha)		46,339	
Number of Stations		25	
Total Fish Abundance (no x1000)		20,147.5	
% CV		14.9%	
Total Fish Biomass (mt)		8,063.4	
% CV		16.4%	
WA San Juan Archipelago			
Area (ha)			86,449
Area w/o rocky area (ha)			80,128
Number of Stations			40
Total Fish Abundance (no x1000)			60,507.3
% CV			14.6%
Total Fish Biomass (mt)			12,353.3
% CV			11.8%
BC Haro Strait and Boundary Pass			
Area (ha)			29,806
Area w/o rocky area (ha)			27,410
Number of Stations			6
Total Fish Abundance (no x1000)			7,437.5
% CV			41.5%
Total Fish Biomass (mt)			1,839.1
% CV			39.0%

The survey precision generally achieved the 30% CV goal for regional estimates of total fish biomass and population abundance. The precision goals were generally achieved, but the potential bias of the trawl survey could not be evaluated. The abundance and biomass estimates resulting from a trawl survey are dependent on a number of assumptions, the foremost of which is that all of the fish and invertebrates are captured in the path of the trawl (Gunderson 1993). The catching process potentially suffers from three sources of bias: vertical herding, horizontal herding, and escapement (Somerton et al. 1999). These assumptions have seldom been verified, but recent work has evaluated herding and net efficiency for a larger version of the research trawl used in the transboundary survey (Somerton and Otto 1999; Somerton and Munro 2001). How the smaller Eastern Trawl performed in terms of bridle and net efficiency are unknown. Other comparison to known population sizes such as those estimated through virtual population analyses, tagging studies, or other comprehensive survey techniques (Somerton et al. 1999) can be used to examine the catchability of trawls. Studies on net efficiency are suggested in order to understand the potential for estimation bias. The WDFW Trawl Survey may be an effective population estimation tool to manage commercial and recreational crab fisheries if such experimental studies are conducted.

Other factors may influence whether the trawl survey estimates reflect the true population of fishes and large invertebrates. Because the survey net and vessel could not sample effectively in waters less than 5 fm depth, segments of the fish population were certainly missed. Shallow water groundfish species and juvenile stages, especially starry flounder which can occur in high abundance in the estuarine portions of Puget Sound rivers (McCain et al. 1982), most likely were underestimated during our survey. Future surveys might consider employing a smaller vessel and net to sample shallow waters as a complimentary survey to the deeper water survey. Migrations of species or stocks within the study area may also affect the conclusions derived for fishery and ecosystem management. If substantial numbers of English sole or other species migrate into or out of the area during the year (Ketchen et al. 1983), then the survey may either overestimate or underestimate the population exposed to fisheries or other ecosystem stressors. Our trawl survey results also underestimated groundfish species that spend substantial time in the midwater. Pacific whiting and walleye pollock are primarily pelagic species and were most likely underestimated.

Time series of comparable bottom trawl survey data are not available for B.C., but bottom trawl surveys in the Washington portions of the Straits of Juan de Fuca and Georgia have been surveyed at irregular intervals since 1987 (Quinnell and Schmitt 1991, Palsson et al. 1997). The biomass of total fish resulting from the 2000 WA Juan de Fuca survey were substantially less than for most previous surveys (Table 2). The 2000 total fish biomass is almost one half less than the 1991 survey estimate, and one third less than the 1987 or 1989 estimates. The 2001 survey in the WA Strait of Georgia was the sixth in a series of bottom trawl surveys and provides the basis to evaluate trends in population abundance from 1987 to 2001. Groundfish biomass increased in the WA Strait of Georgia from 11,000 mt in1997 to 18,000 mt in 2001. Total fish biomass estimated from the 2001 results was the highest point estimate for the WA Strait of Georgia ever recorded (Table 2). However, wide 95% confidence limits encompassed the point estimates of the 1987, 1994, and 1997 surveys indicating stability among recent survey estimates comparable to the first survey estimate. The 95% confidence limits for the 2001 total fish biomass did not overlap the point estimates of the 1989 and 1991 surveys indicating that the 2001 biomass was significantly greater than these earlier estimates. The reasons for such population fluctuations are not clear, particularly in regard to the reverse trends in individual species. Such changes in population may be attributed to increases or decreases in productivity, declines or increases in dominant species, or past or present fishing practices.

Table 2. Total Fish Biomass and Percent Coefficient of Variation for Washington Survey Regions

Region	1987	1989	1991	1994	1997	2000	2001
WA Georgia Strait (mt)	15,849.3	8,681.8	7,618.7	15,090.2	11,056.7		18,370.5
%CV	80.3	25.3	25.9	14.7	21.2		21.4
WA Juan de Fuca (mt)	30,473.2	30,168.6	36,129.1			18,952.3	
%CV	21.5	17.3	26.0			12.4	

Several distinct patterns in transboundary distributions were observed that have implications for coordinated fisheries management between the United States and Canada. In the Strait of Georgia, the deep Malaspina Trough confines shallow-water species to the rim around the basin. These species are less likely to be encountered by trans-border fisheries. Deep-water species, however, were distributed along the international border making them vulnerable to fisheries on either side of the border. The banks and troughs of the eastern Strait of Juan de Fuca presented a different pattern of species distributions. Shallow and deep-water species were distributed on either side of the international boundary making them both likely to be encountered by transboundary fisheries.

The limited surveys of the BC Strait of Georgia and Haro Strait-Boundary Pass were not very useful because of low sample sizes or limited area coverage. In order to compare transboundary and time trends, expanded bottom trawl surveys are suggested as a means to monitor fish and invertebrate populations shared by WA and BC and to provide a basis to evaluate the effectiveness of habitat and population conservation measures that have been implemented during recent years.

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